TOPEX Altimeter Range Stability Estimates from Calibration Mode Data

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Introduction

From launch and continuing through the life of the mission our group in the Observational Science Branch at the Wallops Flight Facility (WFF) has been conducting performance analysis and engineering assessment for the NASA radar altimeter of TOPEX/POSEIDON (hereafter referred to as the TOPEX altimeter). We report here the results to date for estimation of range bias changes for the TOPEX altimeter based on data from its internal calibration mode.

Description of TOPEX Calibration Mode

The TOPEX altimeter has an internal calibration mode which has two parts or submodes, referred to as Cal-1 and Cal-2. Cal-1 was designed to detect changes in the internal path delays to measure range drift. The design requirement was to maintain calibration for drift to within ±1.5 cm. Cal-1 also monitors changes in the receiver automatic gain control (AGC); the altimeter's estimates of the ocean surface radar backscattering cross-section are obtained from the AGC values. The second mode, Cal-2, is to characterize the response of the receiver and digital filter bank.

When commanded to calibration mode, the TOPEX altimeter first enters Cal-1 and then Cal-2. The entire calibration mode (Cal-1 and Cal-2) lasts about 4 minutes. Early in the mission there were four TOPEX altimeter calibrations commanded per day, but now there are usually two per day. The calibration mode is normally scheduled over land, to avoid loss of over-ocean data.

In Cal-1 a portion of the transmitter output is fed back to the receiver through a digitally controlled calibration attenuator and a delay line. The altimeter acquires and tracks this calibration signal for 10 seconds for each of 17 different preset attenuator values (in a series of 2 dB steps). Then in Cal-2 the altimeter processes receiver thermal noise, with no transmitted signal present, to characterize the waveform sampler response. The Cal-2 data are important for the backscattering power measurements, but this paper concentrates on the Cal-1 information about changes in internal system delays as these changes affect range estimation.

Processing for Calibration Mode Data

Routine WFF processing and databases

As part of our continuing TOPEX support, we do daily quick-look processing of all TOPEX altimeter data for performance monitoring, providing performance summaries of all engineering and science data. The daily processing results are used to update a launch-to-date engineering database. Also the daily two sets of calibration mode data are processed, and these results update a launch-to-date calibration database. We also process the intermediate geophysical data record (IGDR) data as it becomes available for network access, normally about 7 days after the altimeter acquires the data. The data are processed for altimeter performance, and one-minute summary records update our launch-to-date IGDR database. The combination of our several launch-to-date databases provides us with a unique capability for the long term performance monitoring of the TOPEX altimeter.

The results reported here are based on our calibration database, with temperatures obtained from our engineering database. The calibration database contains, as of early October 1994, entries from over 1400 separate sets of calibration mode data in the more than two years of TOPEX altimeter operation. A constant range is subtracted from the calibration range values before they are entered in our calibration database, and we refer to these reduced range values as **delta** ranges in the following. The constant range values (one each for the Ku-band and the C-band systems in the TOPEX altimeter) were chosen so that the delta ranges at data cycle 009 would be close to zero. Cycle 009 was chosen as the baseline for the calibration database because the TOPEX/POSEIDON attitude control had been improved by that point and the temperatures and satellite operating conditions had become stable.

Quantization in digital filter bank positioning

One significant problem with the TOPEX altimeter's calibration mode arises from the 7.3 mm least significant bit in the digital word which positions the altimeter's digital filter bank (DFB) in calibration mode operation. (In normal tracking, the DFB positioning has a much smaller least significant bit.) This calibration mode DFB positioning quantization, together with the almost noise-free character of the signal being tracked in Cal-1, results in a range vs. time signal which has a regular triangular wave appearance. Our ground processing of for the calibration mode forms a nine-second average of this triangular wave in range; the error in this average relative to the true value of range is a function of where the true range is located relative to the 7.3 mm quantization steps. Several millimeters of bias change can be obscured by the quantization effect. We have recently developed a method to correct for most of the error, based on simulation work. This method is included now in our routine processing of the calibration mode range data. We have recomputed all the calibration data from launch onwards using our quantization correction, and the recomputed data are shown in this paper's figures. We will not go into further detail here on corrections for DFB positioning quantization, but we can supply more information upon request. Incidentally, we had not corrected for the DFB positioning quantization effect at the time the range constants were chosen for producing the delta ranges in our calibration database; this is why the cycle 009 delta range values are not zero.

Results

<u>Delta combined ranges</u>

Cal-1 provides separate measurements for the Ku-band and the C-band ranges. Remember that TOPEX has both a Ku-band and a C-band altimeter, producing range estimates R_{Ku} and R_C. Both R_{Ku} and R_C have path delay errors caused by ionospheric electron content in the radar path. Because the path delay due to ionospheric electron content is inversely proportional to the radar frequency, a combined ionosphere-corrected range estimate R_{comb} is formed by

$$R_{comb} = [K/(K-1)]R_{Ku} - [1/(K-1)]R_C, \text{ where}$$

$$K = (f_{Ku}/f_C)^2 \text{ and}$$

f_{Ku} and f_C are the Ku-band and C-band radar frequencies. The Cal-1 step-5 Ku- and C-band delta ranges have been processed, by the R_{comb} relationship above, to form a set of delta combined range values. There are about twenty delta combined ranges for each TOPEX data cycle. These have been averaged for each cycle, and the cycle averages are plotted in Figure 1. The error bars in Figure 1 show the standard deviations of the individual delta combined ranges within each cycle average. The data in Figure 1 show a decrease in delta range with increasing cycle number, so that the TOPEX altimeter now appears to be measuring range shorter by about 4 millimeters compared to range measurements in the first 10 data cycles.

<u>Temperature corrections</u>

There are some 26 or so temperature monitors within the TOPEX altimeter. Figure 2 shows the cycle averages for the temperature of the upconverter/frequency multiplier (UCFM), and again the error bars are individual UCFM temperature standard deviations within the cycle averages. Because the Figure 1 delta ranges appeared somewhat correlated with the UCFM temperature data in Figure 2, we did a least-squares fit of the full set of delta combined ranges to a quadratic function of time and then plotted the fit residuals versus

UCFM temperatures as shown in Figure 3. There is an obvious temperature correlation, with the delta combined range decreasing by almost 2 mm for a 1.5 degree increase in UCFM temperature. The solid line in Figure 3 is a quadratic function of cycle number which was fitted to the residuals. Only data from cycle 009 and above were used in this temperature analysis and in Figure 3.

Final temperature-corrected results

We then used the fitted quadratic function to correct the individual calibration delta combined ranges, and then formed cycle averages of these temperature-corrected delta ranges with the result plotted in Figure 4. Comparing Figures 4 and 1, the temperature corrections seem to have reduced some of the larger standard deviations of Figure 1, although some of the smallest standard deviations actually increased a bit. The Figure 4 temperature-corrected cycle averages lie on a somewhat smoother trend than the Figure 1 averages, but the overall trend with increasing cycle number is about the same. The data plotted in Figure 4 are also listed in Table 1.

Conclusion and Summary

We have presented delta range data from the TOPEX altimeter's Cal-1 step-5 for data cycles 001 through 075. These data have been corrected for a DFB positioning quantization error and further adjusted for a temperature dependence. There has been a decrease in range of about 5 mm over the 75 cycles. We believe this is a real effect, although we do have doubts about the DFB quantization correction at levels of a millimeter or less. Since the altimeter is measuring shorter range with increasing cycle number, the sea surface height values will appear to increase with increasing cycle number. Our Table 1 supplies the delta range values for TOPEX data users who want to remove this small trend from their data. We will continue our analyses of calibration data throughout the life of the mission, and will publish updates to this work as appropriate.

Table 1. TOPEX Delta Combined (Ku&C) Range Values from Cal-1 Step-5

Data cycle	Number of Cal Modes	Cycle average delta range, mm	Cycle delta range std. deviation, mm	Data cycle	Number of Cal Modes	Cycle average delta range, mm	Cycle delta range std. deviation, mm
1	16	2.11	0.73	38	19	0.63	0.19
2	19	1.69	0.73	39	20	0.64	0.28
3	18	1.86	1.09	40	21	0.61	0.21
4	18	1.74	0.82	42	20	0.16	0.41
5	20	1.64	0.68	43	20	0.03	0.29
6	20	2.27	0.58	44	18	-0.02	0.32
7	14	2.07	0.58	45	20	0.15	0.24
8	18	1.55	0.37	46	19	0.16	0.50
9	17	1.46	0.51	47	19	-0.56	0.40
10	20	1.77	0.56	48	20	0.12	0.35
11	20	2.28	0.46	49	20	-0.28	0.41
12	19	1.95	0.60	50	19	0.15	0.32
13	15	1.48	0.26	51	20	-0.18	0.43
14	17	1.25	0.56	52	20	-0.39	0.32
15	19	1.35	0.65	53	20	-1.13	0.38
16	20	1.79	0.48	54	21	-0.63	0.31
17	21	2.00	0.35	56	20	-0.55	0.68
18	18	1.83	0.36	57	20	-0.72	0.41
19	16	1.09	0.32	58	20	-1.17	0.26
21	20	1.74	0.28	59	20	-1.53	0.44
22	20	1.65	0.51	60	20	-1.71	0.32
23	19	1.49	0.30	61	19	-1.70	0.27
24	21	1.18	0.32	62	20	-1.81	0.24
25	20	1.40	0.39	63	20	-1.83	0.26
26	19	1.11	0.22	64	21	-1.90	0.44
27	21	1.05	0.24	66	20	-1.88	0.18
28	20	1.07	0.27	67	19	-2.02	0.31
29	20	1.00	0.45	68	20	-1.75	0.40
30	19	0.76	0.30	69	20	-1.97	0.30
32	19	0.95	0.15	70	20	-2.36	0.46
33	17	0.59	0.30	71	20	-3.07	0.44
34	20	-0.12	0.44	72	20	-3.72	1.13
35	19	-0.11	0.40	73	19	-2.46	0.26
36	20	-0.23	0.46	74	20	-2.91	0.26
37	18	0.06	0.51	75*	14	-3.06	0.25

* At the time of this work, only the first 2/3 of data cycle 75 had been received.

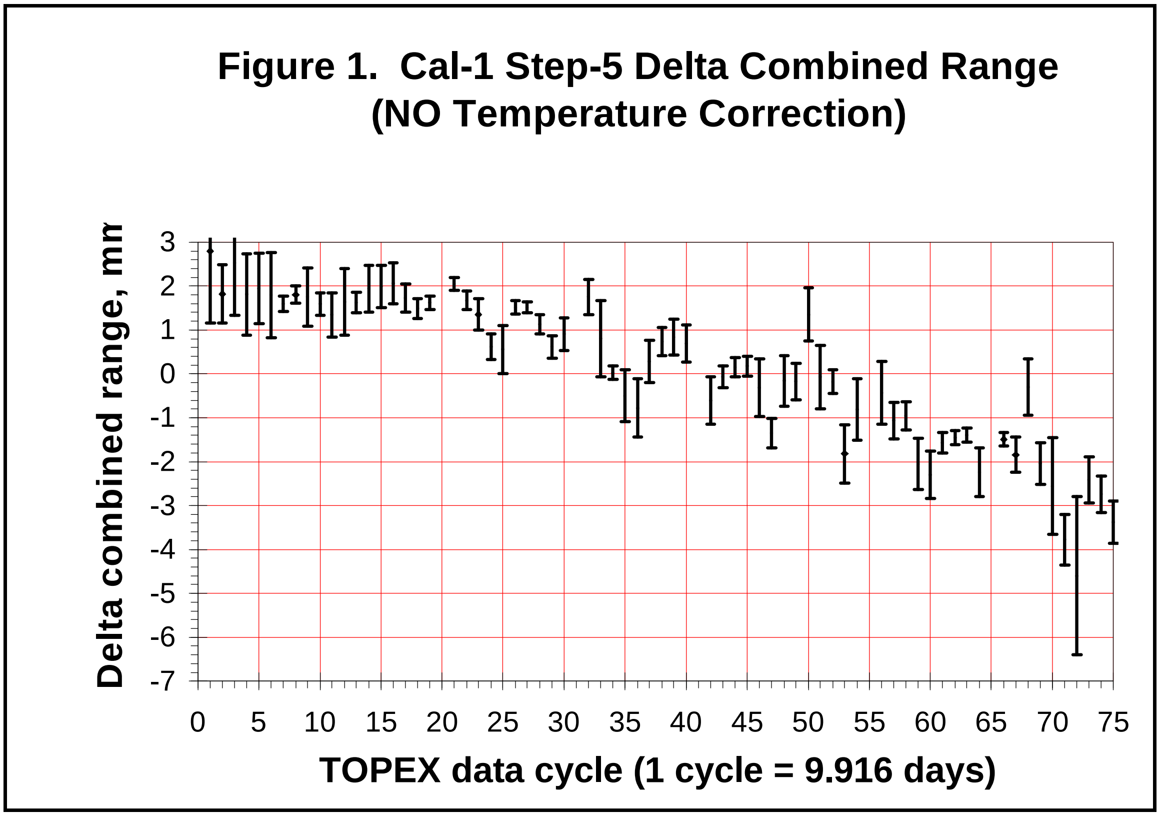
Figure 1. Cal-1 Step-5 Delta Combined Range
(NO Temperature Correction)
Delta combined range, mm
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
TOPEX data cycle (1 cycle = 9.916 days)

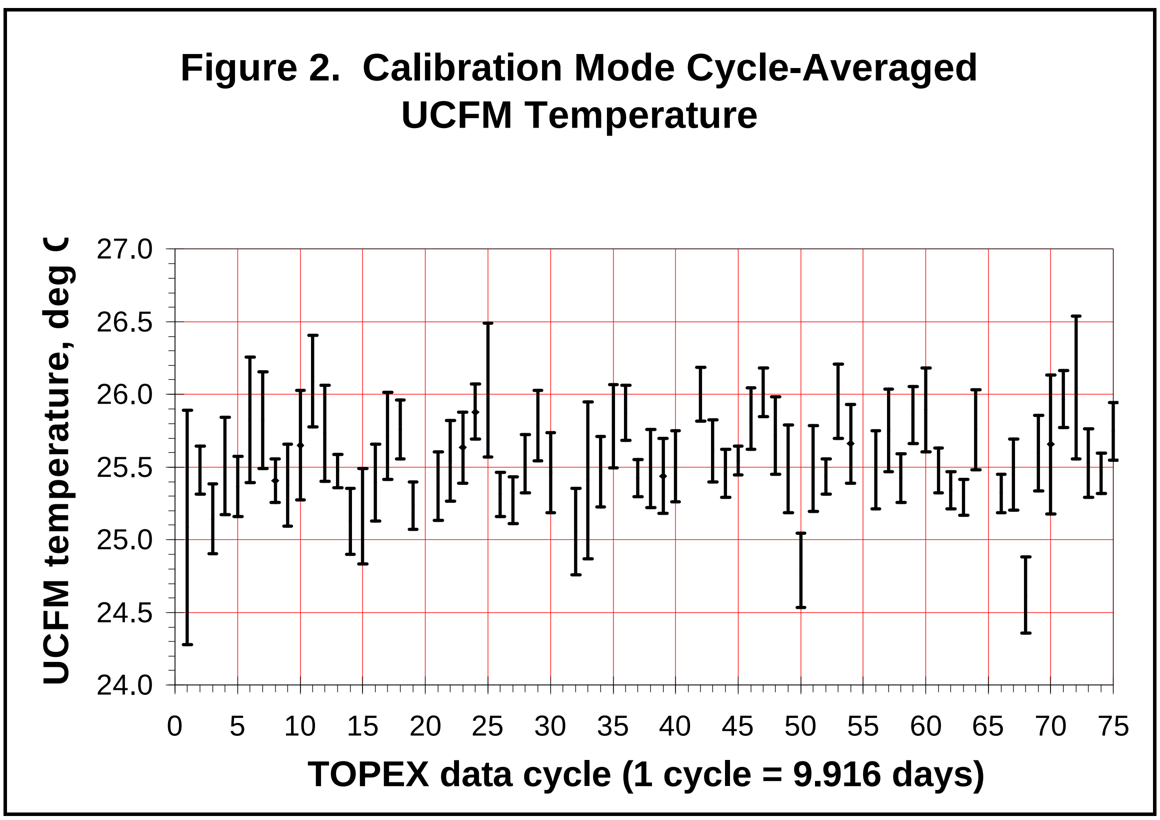
Figure 2. Calibration Mode Cycle-Averaged
UCFM Temperature
UCFM temperature, deg C
27.0
26.5
26.0
25.5
25.0
24.5
24.0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
TOPEX data cycle (1 cycle = 9.916 days)

Figure 3. Cal-1 Step 5 Ku-Band Delta Range Residuals (In - Fit) vs UCFM Temperature

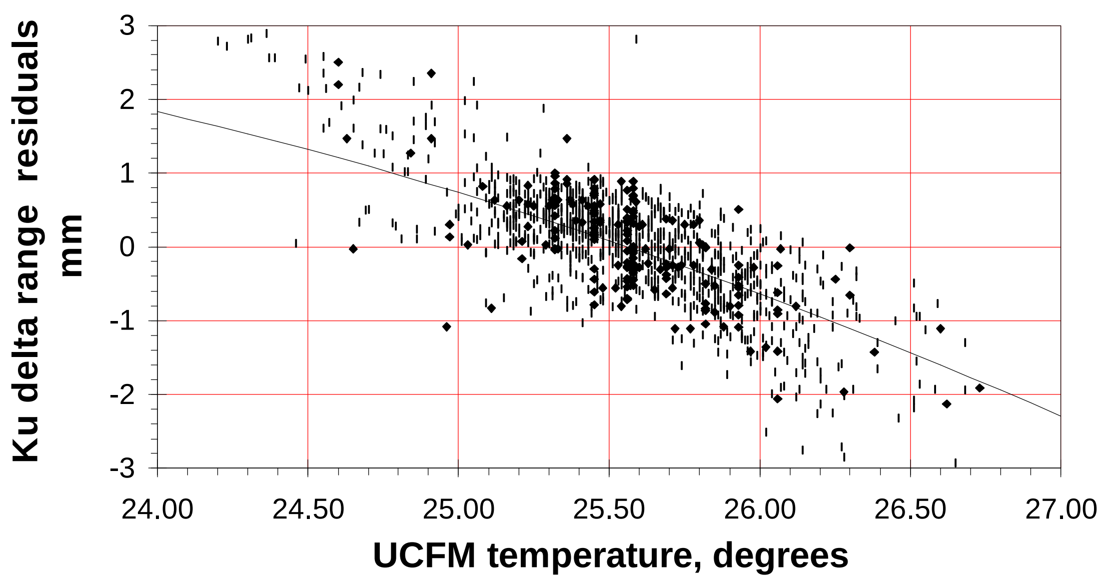

Figure 4. Cal-1 Step-5 Delta Combined Range (WITH Temperature Correction)